Reverberation Modeling and Data Analysis in ASIAEX

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LONG-TERM GOALS

Shallow water acoustics and the performance of sonar systems in littoral environments are critical areas of interest to the US Navy. In response to this, the Office of Naval Research sponsored a series of acoustics experiments in the East and South China Seas, hereafter referred to as ASIAEx. Components of these experiments included studies of shallow water reverberation, geoacoustic properties, and short-range propagation variability. The long-term goals of this study are to provide a better understanding of shallow water reverberation, its statistics, and the primary mechanisms that define its structure, as well as the influence of geoacoustic and water column variability on shallow water propagation. By improving our understanding, the negative influence of such variability on active systems may be reduced through smarter data processing.

OBJECTIVES

The objective of this research was to continue the development of a model capable of computing the influence of propagation on both interface and volume reverberation from a broadband pulse. Spatial correlations and statistics of the predicted reverberant signal were examined. The results from further analysis will be used to compare such predictions with data collected in the recent ASIAEx experiments. By understanding the role of the acoustic propagation in such signals, a clearer description of the underlying dominant scattering mechanisms should emerge. Further objectives also included a study of the impact of bottom variability on effective geoacoustic parameters, most notably compressional attenuation, and a study of the influence of water column variability on short range, water-bourne propagation.

APPROACH

The underlying acoustic model used in this work was the Monterey-Miami Parabolic Equation (MMPE) model.[1] In order to predict reverberation levels, a formal treatment of backscatter was performed in the context of the PE approximation. Essentially, this model incorporates the Born approximation into a two-way PE model, assuming multiple forward scattering occurs due to all environmental fluctuations, but only single backscattering from each scattering patch. Both interface roughness and volume sound speed and density inhomogeneities were treated. It furthermore assumed a constant scattering strength could be used to characterize an entire scattering patch, thereby neglecting much of the details of the specific scattering mechanisms and dominating the result by the total field predicted at the scattering patch. Thus, the statistics and general structure of the predicted reverberation return were solely a function of the propagation. Previous applications of a similar PE

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13. SUPPLEMENTARY NOTES

14. ABSTRACT

Shallow water acoustics and the performance of sonar systems in littoral environments are critical areas of interest to the US Navy. In response to this, the Office of Naval Research sponsored a series of acoustics experiments in the East and South China Seas, hereafter referred to as ASIAEx. Components of these experiments included studies of shallow water reverberation, geoacoustic properties, and short-range propagation variability. The long-term goals of this study are to provide a better understanding of shallow water reverberation, its statistics, and the primary mechanisms that define its structure, as well as the influence of geoacoustic and water column variability on shallow water propagation. By improving our understanding, the negative influence of such variability on active systems may be reduced through smarter data processing.

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reverberation model provided good agreement with reverberation data measured near the mid-Atlantic Ridge [2, 3].

In order to study the influence of bottom variability on geoacoustic inversion properties, a direct approach was taken in which solutions were generated with an without interface and volume perturbations. The perturbations were consistent with those defined in the reverberation modeling analysis. By varying the perturbations and fixing the sediment attenuation in one set, then neglecting the perturbations and varying the sediment attenuation, a direct correlation measure was made to infer the effective attenuation over a range of frequencies. Any observed effective frequency dependence of the attenuation was then due to the influence of the perturbations.

Finally, the analysis of the variability of the water-bourne propagation relies on predictions of the broadband propagation of the 2 msec pulses described in the Melville's Cruise Report from the East China Sea.[4] To this date, the focus has been on the numerical integration of the source properties into the MMPE model, the introduction of simple, internal wave fluctuations, and the extraction of the water-bourne path signal. Once that is obtained, vertical coherence measures are computed across the position of the vertical arrays, as described in [4]. These will be compared with the measured data from the array.

WORK COMPLETED

The theoretical development of the PE reverberation model and the introduction of bottom interface and volume variability was completed in FY00-01. In FY02, the inclusion of sediment density fluctuations was treated, as well as the introduction of measured sound speed profile data, a subbottom interface, and geoacoustic parameters as measured during the East China Sea part of ASIAEX. The work of this past year focussed on the analysis of generated data.

Both interface roughness and sediment sound speed/density fluctuations were computed based on characteristic spectral models of such perturbations. For the reverberation studies, the rms fluctuation of the upper interface ranged from 0.5 – 2 m, the rms fluctuation of the lower interface ranged from 1 – 4 m, and the volume sound speed rms fluctuation ranged from 5 – 45 m/s. Both types of perturbations (interface and volume) were included in all calculations, although the reverberation due to each was considered separately. Thus, it is possible that one type of perturbation may dominate the structure of both types of reverberation. The effects of the variations of the different perturbations on each type of reverberation was examined. From broadband pulse calculations, vertical spatial correlations of the reverberation field were computed. Additionally, the statistical characteristics of the reverberation signal were examined. Such results from future calculations will eventually be compared with measured data to determine the influence of propagation and, hopefully, help discriminate specific scattering mechanisms.

For the effective attenuation studies, the same types of bottom perturbations were included. However, different types of perturbations combinations were employed. In some cases, only a single sediment half-space was defined (no subbottom interface). Calculations were then made which examined only the influence of changes in sediment sound speed gradient, which varied from 0.5 – 2.0 m/s/m. The next set of data were generated with no sound speed gradient, but the bottom interface rms roughness was varied from 1 – 5 m. Next, the interface was flat, but the bottom volume had rms fluctuations ranging from 5 – 15m/s in sound speed (with corresponding fluctuations in bottom density). The

volume fluctuations were then turned off and a subbottom interface was added with rms fluctuations ranging from 1 – 5 m. Finally, an environment was computed with both interfaces of varying roughness and perturbations in the bottom volume. For each of these perturbed environments, the sediment attenuation was held constant. Subsequent to these calculations, a corresponding set of data were computed for the average environment (without perturbations) with varying levels of sediment attenuation. All data was computed over the frequency range from 10 – 500 Hz. By correlating the results of the perturbed and unperturbed data, the effective sediment attenuation as a function of frequency was estimated.

In order to study the variability of the water-bourne propagation path and compare with data collected by Peter Dahl's group at APL-UW, it was necessary to adapt the MMPE model to compute the same type of source response function as used during the experiment. This has been done, and the data can be collected at approximately the appropriate range and depths of the short aperture arrays employed. During FY02, only the basic vertical coherence structures were computed using either range-independent versions of typical water column sound speed profiles or such profiles modified by simple, single-scale internal wave perturbations.

RESULTS

The technique for computing the structure of both CW and broadband reverberation signals was described in the FY00 and FY01 efforts [5, 6].

One of the more interesting results from this year's analysis related to the influence of environmental variability on the vertical coherence of the different types of reverberation. Specifically, it was noted that vertical coherence can sometimes be used to distinguish the dominant type of reverberation appearing in the signal. Figure 1 displays a comparison of the vertical coherence computed from each type of reverberation predicted (water/bottom interface, bottom/subbottom interface, and bottom volume) as the roughness of the interfaces is varied. These results indicate that, while typically the volume reverberation exhibits a more diffuse signal with noticeably less vertical coherence, an increase in interface roughness can cause the subbottom interface reverberation to become so diffuse as to be indistinguishable from the volume reverberation. Contrary to this, examinations of the influence of sound speed profile variations and bottom volume fluctuations did not seem to appreciably affect the coherence structures.

When the influence of environmental fluctuations on the effective frequency dependence of bottom attenuation was examined, it was found that volume and/or subbottom variability introduced the most significant frequency dependence. Specifically, if the bottom volume had a significant sound speed gradient, or if the subbottom interface roughness was significant, lower frequencies penetrating to deeper depths were more likely to be refracted/scattered back into the water column thereby lowering the effective attenuation at those frequencies. A sample log-log plot of effective attenuation versus frequency is provided in Fig. 2. The slope of this line is approximately –0.5, indicating an effective frequency dependence of attenuation of $f^{0.5}$. This is in contrast to some observations at higher frequencies which suggest coefficients > 1.0, and this analysis is on-going to determine what factors may increase the observed coefficient in shallow water environments.
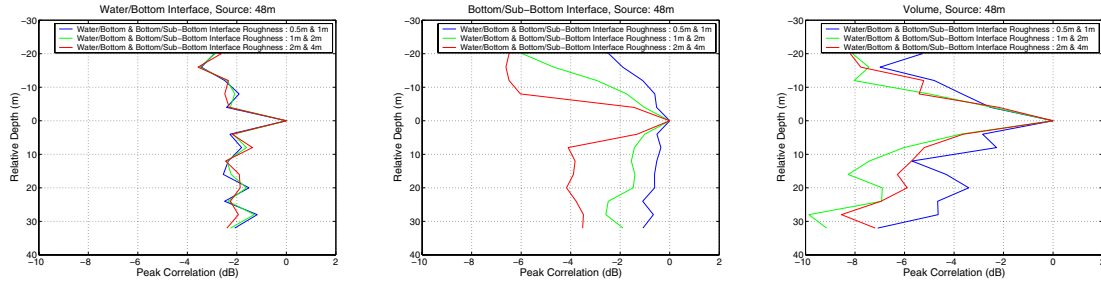
Figure 1: Vertical coherence curves of predicted reverberation from water/bottom interface (left plot), bottom/subbottom interface (middle plot), and bottom volume (right plot). In each plot, the values of rms roughness of the two interfaces are varied. The rms roughness combinations used were (0.5m, 1m) (blue curve), (1m, 2m) (green curve) and (2m, 4m) (red curve) for the (water/bottom, bottom/subbottom) interface, respectively.
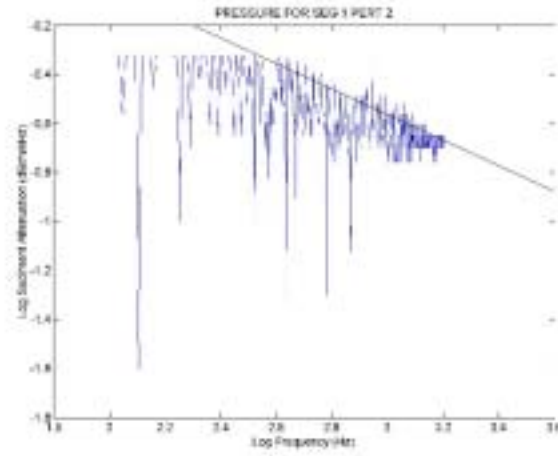

Figure 2: Log-log plot of effective bottom attenuation versus frequency from numerical inversion results. Straight line fitted to majority of data has slope of approximately –0.5.

The analysis of the short-range water-bourne path is on-going. All of the modeling and processing tools are in place and an examination of the influence of different levels of water column variability is underway. Comparison with measured data is expected to occur within the near future.

IMPACT/APPLICATIONS

The ability to distinguish reverberation signals from more general signal returns might lead to an improvement in the performance of active sonar systems. Understanding the influence of environmental variability on effective geoacoustic properties as well as short range propagation may lead to improved propagation prediction capabilities, thereby enhancing our ability to forecast system performance.

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